

## IMAGE PROCESSING APPARATUS, METHOD AND MEMORY MEDIUM

## BACKGROUND OF THE INVENTION

## Field of the Invention

5           The present invention relates to an image processing apparatus for performing an image processing, for example, including a dynamic range compression processing for adding a high frequency component of an original image to the original image  
10       (dynamic range change processing), an image processing system, an image processing method, and a memory medium for storing processing steps to perform the processing in a computer readable manner.

## Related Background Art

15           In recent years, with an advancement of digital technique, for example, a method is executed which comprises: digitizing a photographed image obtained by X-ray photographing (hereinafter also referred to as "X-ray image"), performing an image processing to the  
20       digitized image; and displaying the image on a monitor apparatus, or outputting the image onto an X-ray diagnosis film.

          Here, the X-ray image is constituted of an image area in which it is easy to transmit X-rays, and an  
25       image area in which it is very difficult to transmit the X-rays. For example, the X-ray image of a chest (lungs) is constituted of a lung image area in which it

is easy to transmit the X-rays, and a mediastinum image area in which it is very difficult to transmit the X-rays. In this manner, since the dynamic range in which pixel values are present (hereinafter also referred to as "density range") is much broadened in the X-ray image, it has been difficult to obtain an X-ray image in which both the lung and mediastinum image areas far different in X-ray transmittance from each other can simultaneously be observed.

Therefore, in order to avoid the above-described problem, the following methods 1 to 5 of a dynamic range compression processing (hereinafter also referred to as "DRC processing") have been proposed.

Method 1:

In method 1 described in "SPIE Vol. 626 Medicine XIV/PACSIV (1986)" or the like, assuming that the pixel value of the processed image is " $S_d$ ", the pixel value of the original image (input original image) is " $S_{org}$ ", and the pixel value of the low frequency component of the original image (pixel value of a smoothed image) is " $S_{us}$ ", equation (1) is represented with constants A, B, C (e.g.,  $A = 3$ ,  $B = 0.7$ ).

$$S_d = A[S_{org} - S_{us}] + B[S_{us}] + C \quad (1)$$

Moreover, in the method 1, by changing weighting (constants A and B) of the high frequency component (first term) and low frequency component (second term) in the equation (1) and, for example, assuming  $A = 3$ ,

B = 0.7, the high frequency component is emphasized,  
and the dynamic range of the entire image can be  
compressed. This is evaluated by many radiotherapists,  
et al. such that the image subjected to the present  
5 processing is effective for diagnosis as compared with  
the image not subjected to the present processing.

Method 2:

In a method 2 described in Japanese Patent  
Publication No. 6-046409, assuming that the pixel value  
10 of the processed image is " $S_p$ ", the pixel value of the  
original image is " $S_{org}$ ", and the pixel value of the low  
frequency component of the original image (pixel value  
of the smoothed image) is " $S_{us}$ ", equation (2) is  
represented with a monotonous decrease function  $f(X)$ .

15 
$$S_p = S_{org} + f(S_{us}) \quad (2)$$

Also in this method 2, similarly to the above-  
described method 1, the dynamic range of the entire  
image can be compressed based on the low frequency  
component of the original image.

20 Method 3:

In a method 3 described in Japanese Patent No.  
2509503, assuming that the pixel value of the processed  
image is " $S_p$ ", and the pixel value of the original image  
is " $S_{org}$ ", equation (3) is represented with the average  
25 profile  $P_y$  of the Y-directional profile of the original  
image, and the average profile  $P_x$  of the X-directional  
profile.

$$S_D = S_{org} + F[G(Px, Py)] \quad (3)$$

Here, the property of the function  $F(x)$  in the equation (3) will be described. First, in " $x > Dth$ ",  $F(0)$  is "0". Moreover, in " $0 \leq x \leq Dth$ ",  $F(x)$  monotonously decreases with an intercept "E", and inclination " $E/Dth$ ", and is represented by equation (4).

$$F[x] = E - (E/Dth)X \quad (4)$$

Moreover, the average profiles  $Py$  and  $Px$  in the equation (3) are represented by equations (5) and (6) with profiles  $py_i$  and  $px_i$  ( $i = 1$  to  $n$ ).

$$Py = (\sum Py_i)/n \quad (5)$$

$$Px = (\sum Pxi)/n \quad (6)$$

Moreover, " $G(Px, Py)$ " in the equation (3) is represented by equation (7).

$$G(Px, Py) = \max(px, py) \quad (7)$$

Therefore, in the method 3, the dynamic range is compressed when the pixel value of the low frequency component is  $Dth$  or less.

Method 4:

A method 4 similar to the method 2 described in the Japanese Patent Publication No. 6-046409 and the method 3 described in the Japanese Patent No. 2509503 is described in "Journal of Japanese Society of Radiological Technology, Vol. 45, No. 8, August, 1989, p. 1030, Anan et al".

Assuming that the pixel value of the processed

image is " $S_D$ ", the pixel value of the original image is " $S_{org}$ ", and the average pixel value (pixel value of the smoothed image) obtained by taking the moving average of the original image with a mask size of  $M \times M$  pixels is " $S_{US}$ ", the method 4 is represented by equations (8) and (9) with the monotonous decrease function  $f(X)$ .

$$S_D = S_{org} + f(S_{US}) \quad (8)$$

$$S_{US} = \Sigma S_{org} / M^2 \quad (9)$$

Moreover, the equation (8) can be changed to equation (10).

$$\begin{aligned} S_D &= (S_{org} - S_{US}) + (f(S_{US}) + S_{US}) \\ &= (S_{org} - S_{US}) + f_1(S_{US}) \end{aligned} \quad (10)$$

Here, the method 4 is different from the method 3 represented by the equation (3) in method of generating the low frequency component, the low frequency component is generated with one-dimensional data in the method 3, and the low frequency component is generated by two-dimensional data in the method 4.

Also in the method 4, similarly to the above-described method 3, the dynamic range is compressed when the pixel value of the low frequency component is  $D_{th}$  or less.

Method 5:

For a method 5 described in Japanese Patent No. 2663189, assuming that the pixel value of the processed image is " $S_D$ ", the pixel value of the original image is " $S_{org}$ ", and the average pixel value (pixel value of the

smoothed image) obtained by taking the moving average of the original image with the mask size of  $M \times M$  pixels is " $S_{us}$ ", equations (11) and (12) are represented with the monotonous decrease function  $f2(X)$ .

$$\begin{aligned} S_D &= S_{org} + f2(S_{us}) \\ &= (S_{org} - S_{us}) + f3(S_{us}) \\ f3(S_{us}) &= f2(S_{us}) + S_{us} \end{aligned} \quad (11)$$

$$S_{us} = \Sigma S_{org} / M^2 \quad (12)$$

Here, the property of the function  $f2(x)$  in the equation (11) will be described. First, in " $x < Dth$ ",  $f2(0)$  is "0". Moreover, in " $Dth \leq x$ ",  $f2(x)$  monotonously decreases with the intercept " $E$ ", and inclination " $E/Dth$ ", and is represented by equation (13).

$$f2[x] = E - (E/Dth)X \quad (13)$$

Therefore, in the method 5, the dynamic range is compressed when the low frequency component pixel value is  $Dth$  or less.

Additionally, the compression algorithm of the dynamic range in the method 5 is similar to the algorithm in the method 4 described in the "Journal of Japanese Society of Radiological Technology, Vol. 45, No. 8, August, 1989, p. 1030, Anan et al".

However, the conventional image processing method using the above-described methods 1 to 5 of the DRC processing has at least the following problems 1 and 2.

Problem 1:

For example, as shown in Fig. 14, when the original image (input original image) is subjected to the DRC processing represented by the "Journal of Japanese Society of Radiological Technology, Vol. 45, No. 8, August, 1989, p. 1030, Anan et al.", particularly to the DRC processing including the processing (original image - smoothed image) of subtracting the pixel value  $S_{us}$  of the smoothed image from the pixel value  $S_{org}$  of the original image as shown in the equations (10) and (11), artifacts called overshoot and undershoot are generated in the edge part of the inputted original image.

Concretely, first the cause of the overshoot and undershoot will be described with reference to Figs. 15A, 15B and 15C.

In Figs. 15A, 15B and 15C, solid lines show image profiles, and broken lines show coordinates. Moreover, Fig. 15A shows the profile of the edge part of the original image, Fig. 15B shows the profile of the image (smoothed image) obtained by smoothing the original image, and Fig. 15C shows the profile of the image (corresponding to the image of the high frequency component) obtained after subtracting the smoothed image shown in Fig. 15B from the original image shown in Fig. 15A.

As shown in Fig. 15C, when the original image is

smoothed, the shape of the original image profile is not stored in the edge part. This causes the overshoot and undershoot.

On the other hand, in Fig. 14, the abscissa indicates an image coordinate, and the ordinate indicates an image pixel value. Moreover, in Fig. 14, (A) shows an original image profile. Here, the original image is a step-shaped image in which the pixel value increases by 450 at each 300 pixels, or an image in which the pixel value of 50 as the high frequency component is added to every 50 pixels. Moreover, in Fig. 14, (B) shows the profile of the image obtained by performing the conventional DRC processing to the original image.

Therefore, as apparent from (B) of Fig. 14, since the conventional DRC processing includes a processing of subtracting the smoothed image ( $S_{us}$ ) of the original image from the original image ( $S_{org}$ ) to extract the high frequency component, for the reason described with reference to Fig. 15, the artifacts (overshoot and undershoot) are generated in the edge part of the original image.

#### Problem 2:

The object of the DRC processing by the above-described methods 1 and 2 is to compress the dynamic range of the pixel values of the object area in the image and obtain the image in which the entire object



area can simultaneously be observed.

Therefore, for example, for the lung X-ray image, by compressing the dynamic range of the mediastinum area with a low density in the lung and mediastinum image areas constituting the lung area, it is possible to obtain the image in which both the lung and mediastinum image areas can simultaneously be observed. This is because the density of the low-density side image area is raised to a visible area by compressing the dynamic range of the low-density side image area which is not included in the visible area.

However, in the X-ray image, the low-density side image area of the object area is very low in X-ray transmittance, and usually the S/N ratio also tends to be low as compared with the (high-density side) area high in X-ray transmittance. Therefore, noises are sometimes conspicuous at a certain pixel value or less. In this case, even when the pixel value of the low-density side image area is raised to the visible area by the DRC processing, there is a problem that the effective information of the object area, particularly the information of the low frequency component such as density distribution is obstructed by the noises and cannot easily be observed.

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#### SUMMARY OF THE INVENTION

Therefore, the present invention has been

developed to remove the above-described disadvantages,  
and an object thereof is to provide an image processing  
apparatus in which when a dynamic range compression  
processing is performed, artifacts such as an overshoot  
5 and undershoot are depressed, the amplitude of an image  
high frequency component is held and the width of an  
image density distribution is set to be freely  
adjustable, so that a satisfactory processed image can  
be obtained, an image processing system, an image  
10 processing method, and a memory medium for storing  
process steps to perform the processing in a computer  
readable manner.

To attain the object, according to the present  
invention, there is provided an image processing  
15 apparatus for performing a dynamic range compression  
processing to an arbitrary image to add a high  
frequency component obtained based on the image, and  
the image processing apparatus comprises conversion  
means for converting the magnitude of the amplitude of  
20 the added high frequency component based on the  
magnitude of the high frequency component.

Other objects and characteristics of the present  
invention will be apparent from the following  
description and drawings.

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#### BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a block diagram showing the constitution

of an X-ray photographing apparatus to which the present invention is applied;

Fig. 2 is a block diagram showing the constitution of a dynamic range compression processing circuit of the X-ray photographing apparatus in a first embodiment;

Fig. 3 is a flowchart showing the operation of the dynamic range compression processing circuit;

Fig. 4 is a diagram showing one example of a gradation conversion curve for use in the gradation conversion circuit of the dynamic range compression processing circuit;

Fig. 5 is a diagram showing one example of a high frequency component conversion function for use in the conversion circuit of the dynamic range compression processing circuit;

Fig. 6 is a diagram showing the state of a processed image obtained in the dynamic range compression processing circuit;

Fig. 7 is a block diagram showing the constitution of the dynamic range compression processing circuit of the X-ray photographing apparatus in a second embodiment;

Fig. 8 is a flowchart showing the operation of the dynamic range compression processing circuit;

Fig. 9 is a block diagram showing the constitution of the dynamic range compression processing circuit of

the X-ray photographing apparatus in a third embodiment;

Fig. 10 is a flowchart showing the operation of the dynamic range compression processing circuit;

5        Fig. 11 is a block diagram showing the constitution of the dynamic range compression processing circuit of the X-ray photographing apparatus in a fourth embodiment;

10       Fig. 12 is a flowchart showing the operation of the dynamic range compression processing circuit;

Fig. 13 is a diagram showing one example of the high frequency component conversion function for use in the conversion circuit of the dynamic range compression processing circuit in a fifth embodiment;

15       Fig. 14 is a diagram showing that an overshoot and undershoot are generated in the image by a conventional dynamic range compression processing; and

Figs. 15A, 15B and 15C are explanatory views of the overshoot and undershoot.

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#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Embodiments of the present invention will be described hereinafter with reference to the drawings.  
(First Embodiment)

25       The present invention is applied, for example, to an X-ray photographing apparatus 100 shown in Fig. 1.

This X-ray photographing apparatus 100 has an

image processing function including a dynamic range  
compression processing (DRC processing) and, as shown  
in Fig. 1, comprises: an X-ray generation circuit 101  
for generating X-rays; a two-dimensional X-ray sensor  
5 104 in which the X-ray transmitted through an object  
103 forms an image; a data collection circuit 105 for  
collecting photographed images outputted from the two-  
dimensional X-ray sensor 104; a preprocessing circuit  
106 for performing a preprocessing to the photographed  
10 image collected by the data collection circuit 105; a  
main memory 109 for storing various information of the  
photographed image (original image) subjected to the  
preprocessing in the preprocessing circuit 106 and a  
processing program for executing various processings;  
15 an operation panel 110 for performing instructions for  
execution of X-ray photographing, and the like and  
various settings to the present apparatus; an image  
processing circuit 112 for performing an image  
processing including the DRC processing to the  
20 photographed image (original image) subjected to the  
preprocessing in the preprocessing circuit 106; an  
image display 111 for displaying the processed images  
of the image processing circuit 112; and CPU 108 for  
controlling the entire operation of the present  
25 apparatus. The data collection circuit 105,  
preprocessing circuit 106, image processing circuit  
112, CPU 108, main memory 109, operation panel 110, and

image display 111 are connected to a CPU bus 107 to transmit/receive data with one another.

Moreover, the image processing circuit 112 includes a DRC processing circuit 112a for performing the DRC processing to the original image, a feature extraction circuit 112b for extracting a feature amount from the original image, and a gradation conversion circuit 112c for performing a gradation conversion processing to the processed image of the DRC processing circuit 112a based on the feature amount obtained by the feature extraction circuit 112b.

Here, the DRC processing circuit 112a is constituted to convert the high frequency component in accordance with a high frequency component amplitude when the image high frequency component is added to the original image or the image obtained by smoothing the original image, and constitutes the most characteristic part of the present embodiment.

Therefore, for example, as shown in Fig. 2, the DRC processing circuit 112a includes a gradation conversion circuit 201 for gradation-converting an original image density, a smoothing circuit 202 for smoothing the processed image of the gradation conversion circuit 201, a high frequency component generation circuit 203 for subtracting the smoothed image obtained in the smoothing circuit 202 from the processed image of the gradation conversion circuit 201

to obtain the high frequency component of the image, a conversion circuit 204 for converting the amplitude of the high frequency component obtained by the high frequency component generation circuit 203, and a high frequency component addition circuit 205 for adding the high frequency component converted by the conversion circuit 204 to the processed image of the gradation conversion circuit 201.

Moreover, in the above-described X-ray photographing apparatus 100, first the main memory 109 pre-stores the data necessary for executing various processings in the CPU 108, processing program, and the like, and further includes a work memory for the operation of the CPU 108. As the processing program stored in the main memory 109, particularly as the processing program for the DRC processing, for example, the processing program according to a flowchart of Fig. 3 is used here.

Therefore, by reading and executing the above-described processing program, and the like from the main memory 109, the CPU 108 controls the entire operation of the present apparatus according to the operation from the operation panel 110 as described later.

Step S300:

First, the X-ray generation circuit 101 radiates an X-ray beam 102 to a test object 103. The X-ray beam

102 radiated from the X-ray generation circuit 101 is attenuated and transmitted through the test object 103, reaches the two-dimensional X-ray sensor 104, and is outputted as an X-ray image from the two-dimensional X-ray sensor 104. Here, the X-ray image outputted from the two-dimensional X-ray sensor 104 is used, for example, as a lung X-ray image 300 constituted of a lung field and mediastinum.

Subsequently, the data collection circuit 105 converts the X-ray image outputted from the two-dimensional X-ray sensor 104 to an electric signal, and supplies the signal to the preprocessing circuit 106.

The preprocessing circuit 106 performs preprocessings such as an offset correction processing and a gain correction processing to the signal (X-ray image signal) from the data collection circuit 105. The X-ray image signal subjected to the preprocessing in the preprocessing circuit 106 is transferred as input image information to the main memory 109 and image processing circuit 112 via the CPU bus 107 by the control of the CPU 108.

Subsequently, the DRC processing circuit 112a of the image processing circuit 112 executes the processing of the following steps S301 to S306.

Step S301:

First, the gradation conversion circuit 201 uses, for example, a gradation conversion curve  $F1()$  shown in



Fig. 4 to perform a gradation conversion processing shown in equation (14) to the image (original image) transferred via the CPU bus 107.

$$f0(x,y) = F1(f1(x,y)) \quad (14)$$

5        In the equation (14), "f1(x,y)" indicates the pixel value of the original image (two-dimensional original image) which is a processing object, and "x" and "y" indicate two-dimensional X and Y coordinates of the original image. Moreover, "f0(x,y)" indicates the  
10      pixel value of the original image (output image) after the gradation conversion processing.

         Additionally, the gradation conversion curve F1() shown in Fig. 4 is an example of the gradation  
conversion curve for use in the gradation conversion  
15      circuit 201, and in Fig. 4, the abscissa indicates an input pixel value, and the ordinate indicates an output pixel value.

Step S302:

         Subsequently, the main memory 109 as micro  
20      coefficient memory means uses equation (15) to calculate a micro coefficient c(x) (coefficient for adding the high frequency component) of the gradation conversion curve F1(), and stores the coefficient as a table c(x).

$$25 \quad c(x) = 1 / \frac{\partial F1(x)}{\partial x} \quad (15)$$

         Here, "x" of the equation (15) is used as the

variable indicating the pixel value. Moreover, " $c(x)$ " has a function form in which for example, even when the dynamic range of the original image is changed, the amplitude of the high frequency component of the  
5 changed image matches with the amplitude of the high frequency component of the original image.

Additionally, the conversion curve shown in Fig. 5 is a conversion curve (high frequency component conversion function  $Ch(x)$ ) for use in the processing to  
10 change the high frequency component in the conversion circuit 204 described later, and in Fig. 5, the abscissa indicates the amplitude of the input high frequency component, and the ordinate indicates an output high frequency component obtained by converting  
15 the amplitude of the high frequency component. Moreover, the inclination of the conversion curve shown by (A) of Fig. 5 is set, for example, to "1", and the inclination of the conversion curve shown by (B) is set, for example, to "0.1". Here, the curve  
20 inclinations are experimentally determined in accordance with data properties.

Step S303:

Subsequently, the smoothing circuit 202 performs a smoothing processing shown by equation (16) to an image  
25  $f_0(x,y)$  after the gradation conversion processing of the gradation conversion circuit 201 to form a smoothed image  $f_{us}(x,y)$  of the image  $f_0(x,y)$ .

$$f_{us}(x, y) = \frac{\int_{-d}^d \int_{-d}^d f_0(x+x_1, y+y_1) dx_1 dy_1}{\int_{-d}^d \int_{-d}^d dx_1 dy_1} \quad (16)$$

In the equation (16), "d" indicates the mask size in the smoothing processing.

Additionally, the smoothing processing in the smoothing circuit 202 is not limited to the processing shown by the equation (16) and, for example, a smoothing processing using morphological filter calculation may be used as shown by equations (17) to (20).

$$f_2(x, y) = \min\{f_0(x+x_1, y+y_1) - D(x_1, y_1) \mid x_1 \times x_1 + y_1 \times y_1 \leq r_1 \times r_1\} \quad (17)$$

$$f_3(x, y) = \max\{f_2(x+x_1, y+y_1) + D(x_1, y_1) \mid x_1 \times x_1 + y_1 \times y_1 \leq r_1 \times r_1\} \quad (18)$$

$$f_4(x, y) = \max\{f_3(x+x_1, y+y_1) + D(x_1, y_1) \mid x_1 \times x_1 + y_1 \times y_1 \leq r_1 \times r_1\} \quad (19)$$

$$f_{us}(x, y) = \min\{f_4(x+x_1, y+y_1) - D(x_1, y_1) \mid x_1 \times x_1 + y_1 \times y_1 \leq r_1 \times r_1\} \quad (20)$$

In the equations (17) to (20), "D(x, y)" indicates a disc-shaped filter and is represented by equation (21) with an arbitrary constant r<sub>1</sub> (constant to which a value is set in accordance with the original image, and the like).

$$\begin{aligned} D(x, y) &= 0, \quad x \times x + y \times y \leq r_1 \times r_1 \\ &= -\infty, \quad \text{others} \end{aligned} \quad (21)$$

Step S304:

Subsequently, the high frequency component generation circuit 203 calculates a high frequency component image  $fh(x,y)$  by equation (22) from the image  $f0(x,y)$  after the gradation conversion processing of the gradation conversion circuit 201 and the image  $fus(x,y)$  after the smoothing processing of the smoothing circuit 202.

$$fh(x,y) = c(f1(x,y)) \times (f0(x,y) - fus(x,y)) \quad (22)$$

In the equation (22) " $c(x)$ " indicates the table  $c(x)$  stored beforehand in the main memory 109, that is, the coefficient of the gradation conversion curve  $F()$ . Therefore, the high frequency component image  $fh(x,y)$  obtained here depends on the gradation conversion curve.

Step S305:

Subsequently, the conversion circuit 204 converts the high frequency component image  $fh(x,y)$  obtained in the high frequency component generation circuit 203 to calculate a converted image  $fch(x,y)$  by equation (23) which uses, for example, a high frequency component conversion function  $Ch(x)$  shown in Fig. 5.

$$fch(x,y) = Ch(fh(x,y)) \quad (23)$$

Step S306:

Subsequently, the high frequency component addition circuit 205 adds the converted image  $fch(x,y)$

obtained in the conversion circuit 204 to the image  
fus(x,y) after the smoothing processing in the  
smoothing circuit 202. Specifically, an image fdr(x,y)  
after the final DRC processing is obtained by equation  
5 (24).

$$fdr(x,y) = f0(x,y) + (1-c(fl(x,y))) \times fch(x,y) \quad (24)$$

Here, Fig. 6 shows the profile of the image after  
the final DRC processing obtained in the high frequency  
10 component addition circuit 205. As apparent from Fig.  
6, the change amount of the dynamic range is the same  
as that of the conventional DRC processing shown in  
Fig. 14, but the overshoot and undershoot are  
depressed.

15 Step S307:

As described above, the DRC processing circuit  
112a obtains the image in which the artifacts such as  
the overshoot and undershoot are depressed, and  
supplies the image after the DRC processing to the  
20 gradation conversion circuit 112c.

In this case, the feature extraction circuit 112b  
extracts the feature amount for defining the gradation  
conversion curve for use in the gradation conversion  
circuit 112c from the image (original image)  
25 transferred via the CPU bus 107. Here, since the  
object image is a lung image, for example, the maximum  
pixel value in the lung area is extracted and used as

the feature amount.

The gradation conversion circuit 112c defines the gradation conversion curve so that the feature amount (maximum pixel value) obtained in the feature  
5 extraction circuit 112b indicates a predetermined value (e.g., "1.8"), and uses the curve to perform the gradation conversion to the processed image of the DRC processing circuit 112a.

The processed image of the gradation conversion  
10 circuit 112c is displayed on the screen of the image display 111, or outputted onto the film.

As described above, in the present embodiment, for the high frequency component conversion function  $Ch(x)$  for use in converting the high frequency component, as  
15 shown in Fig. 5, as the absolute value of the high frequency component (input high frequency component) increases, the increase ratio of the absolute value of the converted high frequency component (output high frequency component) monotonously increases. By using  
20 such function, the amplitude of the high frequency component with a large amplitude is depressed with respect to the artifacts such as the overshoot and undershoot, and the amplitude of the frequency component with a small amplitude is unchanged with  
25 respect to the signal component of the object area. Since the high frequency component is converted in this manner, the artifacts can be depressed without dropping

the signal component amplitude. Specifically, since the amplitude of the high frequency component regarded as the artifacts such as the overshoot and undershoot is larger than the amplitude of the high frequency component regarded as effective information, the artifacts can be depressed by the constitution for performing the conversion to depress the amplitude of the large-amplitude high frequency component.

Moreover, in the constitution, since the high frequency component dependent on the gradation conversion curve used in the gradation conversion processing (dependent on the coefficient  $c(x)$  of the gradation conversion curve  $F1()$ ) is added to the original image after the gradation conversion processing, the amplitude of the high frequency component of the image before the gradation conversion processing can be held even in the image after the gradation conversion processing.

(Second Embodiment)

In a second embodiment, in the X-ray photographing apparatus 100 of Fig. 1, the internal constitution of the DRC processing circuit 112a is constituted, for example, as shown in Fig. 7.

Specifically, the above-described first embodiment is constituted such that the high frequency component obtained from the image after the gradation conversion processing is converted, and added to the image after

the gradation conversion processing, but the second  
embodiment is constituted such that the high frequency  
component obtained from the original image before the  
gradation conversion processing is converted and added  
5 to the original image after the gradation conversion  
processing.

Therefore, for example, the processing program  
according to a flowchart of Fig. 8 is used as the  
processing program for the DRC processing here. Since  
10 the processing program is executed by the CPU 108, the  
X-ray photographing apparatus 100 operates as follows  
in the second embodiment.

Additionally, only the constitution different from  
that of the above-described first embodiment will  
15 concretely be described here.

Step S300:

First, similarly to the step S300 of Fig. 3, when  
the X-ray photographing operation starts, the X-ray  
image obtained by the photographing is transferred to  
20 the image processing circuit 112 via the data  
collection circuit 105 and preprocessing circuit 106 by  
the control of the CPU 108.

Subsequently, the DRC processing circuit 112a of  
the image processing circuit 112 executes the  
25 processing of the following steps S311 to S316.

Step S311:

First, a smoothing circuit 211 performs a



smoothing processing shown by equation (25) to the X-ray image (original image)  $f1(x,y)$  transferred by the CPU 108 to form the smoothed image  $fus1(x,y)$  of the original image  $f1(x,y)$ .

$$5 \quad fus1(x,y) = \frac{\int_{-d}^d \int_{-d}^d f1(x+x1, y+y1) dx1 dy1}{\int_{-d}^d \int_{-d}^d dx1 dy1} \quad (25)$$

In the equation (25), "d" indicates a constant for determining the mask size  $M \times M$  in the smoothing processing.

Step S312:

10           Subsequently, a high frequency component generation circuit 212 calculates a high frequency component image  $fhl(x,y)$  by equation (26) from the original image  $f1(x,y)$  transferred by the CPU 108 and the image  $fus1(x,y)$  after the smoothing processing of  
15 the smoothing circuit 211.

$$fhl(x,y) = f1(x,y) - fus1(x,y) \quad (26)$$

Step S313:

            Subsequently, a conversion circuit 213 converts the high frequency component image  $fhl(x,y)$  obtained by  
20 the high frequency component generation circuit 212, and calculates a converted image  $fchl(x,y)$  by equation (27) which uses the high frequency component conversion function  $Ch(x)$  shown in Fig. 5.

$$fchl(x,y) = Ch(fhl(x,y)) \quad (27)$$

Step S314:

Subsequently, a gradation conversion circuit 214 performs a gradation conversion processing shown by equation (28) to the original image transferred by the CPU 108, using the gradation conversion curve  $F1()$  shown in Fig. 4.

$$f0(x,y) = F1(f1(x,y)) \quad (28)$$

In the equation (28), " $f1(x,y)$ " indicates the pixel value of the original image (two-dimensional original image) as the processing object, and " $x$ " and " $y$ " indicate two-dimensional X and Y coordinates of the original image. Moreover, " $f0(x,y)$ " indicates the pixel value of the original image (output image) after the gradation conversion processing.

Step S315:

Subsequently, the main memory 109 as the micro coefficient memory means uses equation (29) to calculate a micro coefficient  $c1(x)$  of the gradation conversion curve  $F1()$ , and stores the coefficient as a table  $c1(x)$ .

$$c1(x) = 1 - \frac{\partial F1(x)}{\partial x} \quad (29)$$

Step S316:

Subsequently, a high frequency component addition circuit 215 adds a converted image  $fclh(x,y)$  of the conversion circuit 213 to the image  $f0(x,y)$  after the gradation conversion processing of the gradation

conversion circuit 214. Specifically, an image  $f_{drl}(x,y)$  after the final DRC processing is calculated by equation (30).

$$f_{drl}(x,y) = f_0(x,y) + c(f_1(x,y)) \times f_{chl}(x,y) \quad (30)$$

5

Step S307:

As described above, the image  $f_{drl}(x,y)$  after the DRC processing obtained by the DRC processing circuit 112a is supplied to the gradation conversion circuit 112c similarly to the step S307 of Fig. 3, subjected to the gradation conversion processing, and subsequently displayed on the screen of the image display 111 or outputted onto the film.

As described above, in the present embodiment, since the high frequency component of the original image before the gradation conversion processing is used to perform the DRC processing, as compared with the DRC processing using the high frequency component of the original image after the gradation conversion processing, the DRC processing can be performed using a more precise (less digit drop) high frequency component. In addition to the effect of the first embodiment, this can provide an effect that a higher frequent component image with a satisfactory restorability can be obtained after the DRC processing.

(Third Embodiment)

25

According to a third embodiment, in the X-ray

photographing apparatus 100 of Fig. 1, the internal constitution of the DRC processing circuit 112a is constituted, for example, as shown in Fig. 9.

Specifically, the above-described first embodiment  
5 is constituted such that the high frequency component obtained from the image after the gradation conversion processing is converted and added to the image after the gradation conversion processing, but the third  
10 embodiment is constituted such that the high frequency component obtained from the original image before the gradation conversion processing is converted and added to the original image after the smoothing processing and gradation conversion processing.

Therefore, for example, the processing program  
15 according to a flowchart of Fig. 10 is used as the processing program for the DRC processing here. Since the processing program is executed by the CPU 108, the X-ray photographing apparatus 100 operates as follows in the third embodiment.

20 Additionally, only the constitution different from that of the above-described first embodiment will concretely be described here.

Step S300:

First, similarly to the step S300 of Fig. 3, when  
25 the X-ray photographing operation starts, the X-ray image obtained by the photographing is transferred to the image processing circuit 112 via the data

collection circuit 105 and preprocessing circuit 106 by the control of the CPU 108.

Subsequently, the DRC processing circuit 112a of the image processing circuit 112 executes the processing of the following steps S321 to S325.

Step S321:

First, a smoothing circuit 221 performs a smoothing processing shown by equation (31) to the X-ray image (original image)  $f1(x,y)$  transferred by the CPU 108 to form the smoothed image  $fus1(x,y)$  of the original image  $f1(x,y)$ .

$$fus1(x,y) = \frac{\int_{-d}^d \int_{-d}^d f1(x+x1, y+y1) dx1 dy1}{\int_{-d}^d \int_{-d}^d dx1 dy1} \quad (31)$$

In the equation (31), "d" indicates the constant for determining the mask size  $M \times M$  in the smoothing processing.

Step S322:

Subsequently, a high frequency component generation circuit 222 calculates a high frequency component image  $fh1(x,y)$  by equation (32) from the original image  $f1(x,y)$  transferred by the CPU 108 and the image  $fus1(x,y)$  after the smoothing processing in the smoothing circuit 221.

$$fh1(x,y) = f1(x,y) - fus1(x,y) \quad (32)$$

Step S323:

Subsequently, a conversion circuit 223 converts the high frequency component image  $fh1(x,y)$  obtained in the high frequency component generation circuit 222, and calculates a converted image  $fch1(x,y)$  by equation (33) which uses the high frequency component conversion function  $Ch(x)$  shown in Fig. 5.

$$fch1(x,y) = Ch(fh1(x,y)) \quad (33)$$

Step S324:

Subsequently, a gradation conversion circuit 224 performs a gradation conversion processing shown by equation (34) to the image  $fus1(x,y)$  after the smoothing processing of the smoothing circuit 221, using the gradation conversion curve  $F1()$  shown in Fig. 4.

$$fus2(x,y) = F1(fus1(x,y)) \quad (34)$$

In the equation (34), " $fus2(x,y)$ " indicates the pixel value of the smoothed image (output image) after the gradation conversion processing.

Step S325:

Subsequently, a high frequency component addition circuit 225 adds the converted image  $fclh(x,y)$  of the conversion circuit 223 to the image  $fus2(x,y)$  (image after the smoothing processing and gradation conversion processing) after the gradation conversion processing of the gradation conversion circuit 224. Specifically, an image  $fdr2(x,y)$  after the final DRC processing is calculated by equation (35).

$$fdr2(x,y) = fus2(x,y) + fch1(x,y) \quad (35)$$

Step S307:

As described above, the image  $fdr2(x,y)$  after the DRC processing obtained by the DRC processing circuit 112a is supplied to the gradation conversion circuit 112c similarly to the step S307 of Fig. 3, subjected to the gradation conversion processing, and subsequently displayed on the screen of the image display 111 or outputted onto the film.

As described above, in the third embodiment, since the high frequency component of the original image before the gradation conversion processing is used, and the converted component is added to the image after the smoothing processing and gradation conversion processing, as compared with the DRC processing in which the high frequency component of the original image after the gradation conversion is used, the DRC processing can be performed using a more precise (less digit drop) high frequency component. In addition to the effect of the first embodiment, this can provide an effect that a higher frequent component image with a satisfactory restorability can be obtained after the DRC processing. Furthermore, since the gradation conversion is performed after obtaining and converting the high frequency component, in the above-described first (or second) embodiment, the processing of calculating and storing the coefficient  $c(x)$  of the

gradation conversion curve  $F()$  is unnecessary. In the gradation conversion of the original image, the high frequency component needs to be considered in the gradation conversion, but in the third embodiment, the smoothed image (image with no high frequency component) is subjected to the gradation conversion, and the high frequency component does not have to be considered in the gradation conversion. Therefore, the processing time can be shortened.

10 (Fourth Embodiment)

According to a fourth embodiment, in the X-ray photographing apparatus 100 of Fig. 1, the internal constitution of the DRC processing circuit 112a is constituted, for example, as shown in Fig. 11.

15 Specifically, the above-described first embodiment is constituted such that the high frequency component obtained from the image after the gradation conversion processing is converted and added to the image after the gradation conversion processing, but the fourth  
20 embodiment is constituted such that the high frequency component obtained from the original image before the gradation conversion processing is converted, added to the original image, and subsequently subjected to the gradation conversion processing.

25 Therefore, for example, the processing program according to a flowchart of Fig. 12 is used as the processing program for the DRC processing here. Since



the processing program is executed by the CPU 108, the X-ray photographing apparatus 100 operates as follows in the fourth embodiment.

Additionally, only the constitution different from  
5 that of the above-described first embodiment will concretely be described here.

Step S300:

First, similarly to the step S300 of Fig. 3, when the X-ray photographing operation starts, the X-ray  
10 image obtained by the photographing is transferred to the image processing circuit 112 via the data collection circuit 105 and preprocessing circuit 106 by the control of the CPU 108.

Subsequently, the DRC processing circuit 112a of  
15 the image processing circuit 112 executes the processing of the following steps S331 to S335.

Step S331:

First, a smoothing circuit 231 performs a smoothing processing shown by equation (36) to the X-ray image (original image)  $f1(x,y)$  transferred by the  
20 CPU 108 to form the smoothed image  $fus1(x,y)$  of the original image  $f1(x,y)$ .

$$fus1(x,y) = \frac{\int_{-d}^d \int_{-d}^d f1(x+x1, y+y1) dx1 dy1}{\int_{-d}^d \int_{-d}^d dx1 dy1} \quad (36)$$

In the equation (36), "d" indicates the constant for

determining the mask size  $M \times M$  in the smoothing processing.

Step S332:

Subsequently, a high frequency component  
5 generation circuit 232 calculates a high frequency component image  $fhl(x,y)$  by equation (37) from the original image  $fl(x,y)$  transferred by the CPU 108 and the image  $fusl(x,y)$  after the smoothing processing of the smoothing circuit 231.

10 
$$fhl(x,y) = fl(x,y) - fusl(x,y) \quad (37)$$

Step S333:

Subsequently, a conversion circuit 233 converts the high frequency component image  $fhl(x,y)$  obtained by the high frequency component generation circuit 232,  
15 and calculates a converted image  $fchl(x,y)$  by equation (38) which uses the high frequency component conversion function  $Ch(x)$  shown in Fig. 5.

$$fchl(x,y) = Ch(fhl(x,y)) \quad (38)$$

Step S334:

20 Subsequently, the main memory 109 as the micro coefficient memory means uses equation (39) to calculate the micro coefficient  $c1(x)$  of the gradation conversion curve  $F1()$  for use in a gradation conversion circuit 235, and stores the coefficient as a table  
25  $c2(x)$ .

$$c2(x) = 1 / \frac{\partial F1(x)}{\partial x} - 1 \quad (39)$$

Step S335:

A high frequency component addition circuit 234 adds the converted image  $fclh(x,y)$  of the conversion circuit 233 to the original image  $f1(x,y)$ .

5 Specifically, an image  $fad(x,y)$  after the addition of the high frequency component is calculated by equation (40).

$$fad(x,y) = f1(x,y) + c2(f1(x,y)) \times fchl(x,y) \quad (40)$$

10 Step S336:

Subsequently, the gradation conversion circuit 235 uses the gradation conversion curve  $F1()$  shown in Fig. 4 and performs a gradation conversion processing shown by equation (41) to the image  $fad(x,y)$  obtained by the high frequency component addition circuit 234 to obtain the image  $fdr2(x,y)$  after the final DRC processing.

$$fdr2(x,y) = F1(fad(x,y)) \quad (41)$$

Step S307:

The above-described image  $fdr2(x,y)$  after the DRC processing obtained by the DRC processing circuit 112a is supplied to the gradation conversion circuit 112c similarly to the step S307 of Fig. 3, subjected to the gradation conversion processing, and subsequently displayed on the screen of the image display 111 or outputted onto the film.

25 As described above, in the fourth embodiment, since the high frequency component of the original

image before the gradation conversion processing is used to perform the DRC processing, as compared with the DRC processing in which the high frequency component of the original image after the gradation conversion processing is used, the DRC processing can be performed using a more precise (less digit drop) high frequency component. In addition to the effect of the first embodiment, this can provide an effect that a higher frequent component image with a satisfactory restorability can be obtained after the DRC processing. (Fifth Embodiment)

In the above-described first to fourth embodiments, by using the high frequency component conversion function shown in Fig. 5 to convert the magnitude of the amplitude of the high frequency component obtained from the original image or the image obtained by smoothing the original image in accordance with the magnitude of the high frequency component, the artifacts such as the overshoot and undershoot are depressed.

On the other hand, in a fifth embodiment, for example, by using a high frequency component conversion function as shown in Fig. 13 to convert the magnitude of the amplitude of the high frequency component obtained from the original image or the smoothed image of the original image in accordance with the magnitude of the pixel value, the emphasis of the noise is

depressed. The fifth embodiment will concretely be described hereinafter.

Additionally, here, the embodiments for using the high frequency component conversion function of Fig. 13 to convert the high frequency component in the conversion processing 204, 213, 223, 233 of the above-described first to fourth embodiments will be described hereinafter as first' to fourth' embodiments.

Moreover, since the constitution of the DRC processing circuit 112a in the fifth embodiment is similar to the internal constitution of the DRC processing circuit 112a in the first to fourth embodiments shown in Figs. 2, 3, and 7 to 12, these drawings will be used in the following description.

(1) First' Embodiment: See Figs. 2 and 3

Step S300:

First, as described above, when the X-ray photographing operation starts, the X-ray image obtained by the photographing is transferred to the image processing circuit 112 via the data collection circuit 105 and preprocessing circuit 106 by the control of the CPU 108.

Subsequently, the DRC processing circuit 112a of the image processing circuit 112 executes the processing of the following steps S301 to S306.

Step S301:

First, the gradation conversion circuit 201 uses

the gradation conversion curve  $F1()$  defined by the feature amount extracted by the feature extraction circuit 112b and shown in Fig. 4 to perform the gradation conversion processing shown in the equation (14) to the image (original image) transferred via the CPU bus 107.

$$f0(x,y) = F1(f1(x,y)) \quad (14)$$

In the equation (14), " $f1(x,y)$ " indicates the pixel value of the original image (two-dimensional original image) which is a processing object, and " $x$ " and " $y$ " indicate two-dimensional X and Y coordinates of the original image. Moreover, " $f0(x,y)$ " indicates the pixel value of the original image (output image) after the gradation conversion processing.

Step S302:

Subsequently, the main memory 109 as the micro coefficient memory means uses the equation (15) to calculate the micro coefficient  $c(x)$  (coefficient for adding the high frequency component) of the gradation conversion curve  $F1()$ , and stores the coefficient as the table  $c(x)$ .

$$c(x) = 1 / \frac{\partial F1(x)}{\partial x} \quad (15)$$

Here, " $x$ " of the equation (15) is used as the variable indicating the pixel value. Moreover, " $c(x)$ " has a function form in which for example, even when the dynamic range of the original image is changed, the

amplitude of the high frequency component of the changed image matches with the amplitude of the high frequency component of the original image.

Additionally, in the processing of changing the high frequency component as described later, this applies to a case in which the high frequency component conversion function of Fig. 13 is used as the conversion curve for use in the processing and the high frequency component is not changed.

10           Additionally, the high frequency component conversion function in the present embodiment shown in Fig. 13 is one example of the conversion curve for use in the processing to change the high frequency component in the conversion circuit 204, and in Fig. 15   13, the abscissa indicates the pixel value, and the ordinate indicates a coefficient to be multiplied by the high frequency component.

Step S303:

20           Subsequently, the smoothing circuit 202 performs the smoothing processing shown by the equation (16) to the image  $f_0(x,y)$  after the gradation conversion processing in the gradation conversion circuit 201 to form the smoothed image  $f_{us}(x,y)$  of the image  $f_0(x,y)$ .

$$f_{us}(x,y) = \frac{\int_{-d}^d \int_{-d}^d f_0(x+x_1, y+y_1) dx_1 dy_1}{\int_{-d}^d \int_{-d}^d dx_1 dy_1} \quad (16)$$

In the equation (16), "d" indicates the constant for determining the mask size  $M \times M$  in the smoothing processing.

5 Additionally, the smoothing processing in the smoothing circuit 202 is not limited to the processing shown by the equation (16) and, for example, the smoothing processing which uses the morphological filter calculation may be used as shown by equations (17) to (20).

$$10 \quad f_2(x, y) = \min\{f_0(x+x_1, y+y_1) - D(x_1, y_1) \mid x_1 \times x_1 + y_1 \times y_1 \leq r_1 \times r_1\} \quad (17)$$

$$f_3(x, y) = \max\{f_2(x+x_1, y+y_1) + D(x_1, y_1) \mid x_1 \times x_1 + y_1 \times y_1 \leq r_1 \times r_1\} \quad (18)$$

$$15 \quad f_4(x, y) = \max\{f_3(x+x_1, y+y_1) + D(x_1, y_1) \mid x_1 \times x_1 + y_1 \times y_1 \leq r_1 \times r_1\} \quad (19)$$

$$f_{us}(x, y) = \min\{f_4(x+x_1, y+y_1) - D(x_1, y_1) \mid x_1 \times x_1 + y_1 \times y_1 \leq r_1 \times r_1\} \quad (20)$$

In the equations (17) to (20), "D(x,y)" indicates the disc-shaped filter and is represented by the equation (21) with the arbitrary constant  $r_1$  (constant to which the value is set in accordance with the original image, and the like).

$$20 \quad \begin{aligned} D(x, y) &= 0, \quad x \times x + y \times y \leq r_1 \times r_1 \\ &= -\infty, \quad \text{others} \end{aligned} \quad (21)$$

25 By using the morphological filter calculation to perform the smoothing processing, the structure of the original image can be held even in the edge part of the



original image, so that the artifacts such as the overshoot and undershoot can be depressed.

Step S304:

Subsequently, the high frequency component  
5 generation circuit 203 calculates the high frequency  
component image  $fh(x,y)$  by the equation (22) from the  
image  $f0(x,y)$  after the gradation conversion processing  
of the gradation conversion circuit 201 and the image  
 $fus(x,y)$  after the smoothing processing in the  
10 smoothing circuit 202.

$$fh(x,y) = c(f1(x,y)) \times (f0(x,y) - fus(x,y)) \quad (22)$$

Step S305:

Subsequently, the conversion circuit 204 converts  
15 the high frequency component image  $fh(x,y)$  obtained in  
the high frequency component generation circuit 203 to  
calculate the converted image  $fch(x,y)$  by equation  
(23') based on the high frequency component conversion  
function  $Ch(x)$  of Fig. 13.

$$20 \quad fch(x,y) = Ch(f1(x,y)) \times fh(x,y) \quad (23')$$

Additionally, the high frequency component  
conversion function  $Ch(x)$  of Fig. 13 may have any  
function system as long as the coefficient of the area  
in which the high frequency component amplitude is to  
25 be depressed is subtracted. Moreover, the original  
image  $f1(x,y)$  is used as the image in the coefficient  
"Ch()" here, but this is not limited, and for example,

the image obtained after smoothing the original image,  
the image after the gradation conversion of the  
original image, or the image smoothed after the  
gradation conversion of the original image may be used.

5 Step S306:

Subsequently, the high frequency component  
addition circuit 205 adds the converted image  $fch(x,y)$   
obtained in the conversion circuit 204 to the image  
 $fus(x,y)$  after the smoothing processing in the  
10 smoothing circuit 202. Specifically, the image  
 $fdr(x,y)$  after the final DRC processing is calculated  
by equation (24' ).

$$fdr(x,y) = f0(x,y) + (1-1/c(f1(x,y))) \times fch(x,y) \quad (24')$$

15 Step S307:

Thereafter, as described above, the image  
 $fdr1(x,y)$  after the DRC processing obtained by the DRC  
processing circuit 112a is supplied to the gradation  
conversion circuit 112c, subjected to the gradation  
20 conversion processing, and displayed on the screen of  
the image display 111 or outputted onto the film.

As described above, in the constitution of the  
present embodiment, since the high frequency component  
dependent on the gradation conversion curve used in the  
25 gradation conversion processing (dependent on the  
coefficient  $c(x)$  of the gradation conversion curve  
 $F1()$ ) is added to the original image after the

gradation conversion processing, the amplitude of the high frequency component of the image before the gradation conversion processing can be held even in the image after the gradation conversion processing.

5 Moreover, since the high frequency component of the noise area is not restored, the image area of the low frequency component of the noise area can easily be observed. Furthermore, by using the morphological filter calculation in the smoothing processing, the  
10 structure of the original image can be held even in the edge part of the original image, so that the artifacts such as the overshoot and undershoot can be depressed.

(2) Second' Embodiment: see Figs. 7 and 8

Step S300:

15 First, as described above, when the X-ray photographing operation starts, the X-ray image obtained by the photographing is transferred to the image processing circuit 112 via the data collection circuit 105 and preprocessing circuit 106 by the  
20 control of the CPU 108.

Subsequently, the DRC processing circuit 112a of the image processing circuit 112 executes the processing of the following steps S311 to S316.

Step S311:

25 First, the smoothing circuit 211 performs the smoothing processing shown by the equation (25) to the X-ray image (original image)  $f_1(x,y)$  transferred by the

CPU 108 to form the smoothed image  $f_{us1}(x,y)$  of the original image  $f_1(x,y)$ .

$$f_{us1}(x,y) = \frac{\int_{-d}^d \int_{-d}^d f_1(x+x_1, y+y_1) dx_1 dy_1}{\int_{-d}^d \int_{-d}^d dx_1 dy_1} \quad (25)$$

In the equation (25), "d" indicates the constant  
5 for determining the mask size  $M \times M$  in the smoothing processing.

Step S312:

Subsequently, the high frequency component  
generation circuit 212 calculates the high frequency  
10 component image  $f_{h1}(x,y)$  by the equation (26) from the original image  $f_1(x,y)$  transferred by the CPU 108 and the image  $f_{us1}(x,y)$  after the smoothing processing of the smoothing circuit 211.

$$f_{h1}(x,y) = f_1(x,y) - f_{us1}(x,y) \quad (26)$$

15 Step S313:

Subsequently, the conversion circuit 213 converts the high frequency component image  $f_{h1}(x,y)$  obtained in the high frequency component generation circuit 212, and calculates the converted image  $f_{ch1}(x,y)$  by  
20 equation (27') based on the high frequency component conversion function  $Ch(x)$  of Fig. 13.

$$f_{ch1}(x,y) = Ch(f_1(x,y)) \times f_{h1}(x,y) \quad (27')$$

Step S314:

Subsequently, the gradation conversion circuit 214



calculated by the equation (30).

$$\text{fdr1}(x,y) = \text{f0}(x,y) + c(\text{f1}(x,y)) \times \text{fchl}(x,y) \quad (30)$$

Step S307:

5           Thereafter, as described above, the image  
  
           $\text{fdr1}(x,y)$  after the DRC processing obtained by the DRC  
          processing circuit 112a is supplied to the gradation  
          conversion circuit 112c, subjected to the gradation  
          conversion processing, and subsequently displayed on  
10          the screen of the image display 111 or outputted onto  
          the film.

          As described above, in the present embodiment,  
          since the high frequency component of the original  
          image before the gradation conversion processing is  
15          used to perform the DRC processing, as compared with  
          the DRC processing which uses the high frequency  
          component of the original image after the gradation  
          conversion processing, the DRC processing can be  
          performed using a more precise (less digit drop) high  
20          frequency component. In addition to the effect of the  
          first' embodiment, this can provide an effect that a  
          higher frequent component image with a satisfactory  
          restorability can be obtained after the DRC processing.

(3) Third' Embodiment: see Figs. 9 and 10

25          Step S300:

          First, as described above, when the X-ray  
          photographing operation starts, the X-ray image

obtained by the photographing is transferred to the image processing circuit 112 via the data collection circuit 105 and preprocessing circuit 106 by the control of the CPU 108.

- 5           Subsequently, the DRC processing circuit 112a of the image processing circuit 112 executes the processing of the following steps S321 to S325.

Step S321:

- 10           First, the smoothing circuit 221 performs the smoothing processing shown by the equation (31) to the X-ray image (original image)  $f1(x,y)$  transferred by the CPU 108 to form the smoothed image  $fus1(x,y)$  of the original image  $f1(x,y)$ .

$$fus1(x,y) = \frac{\int_{-d}^d \int_{-d}^d f1(x+x1, y+y1) dx1 dy1}{\int_{-d}^d \int_{-d}^d dx1 dy1} \quad (31)$$

- 15           In the equation (31), "d" indicates the constant for determining the mask size  $M \times M$  in the smoothing processing.

Step S322:

- 20           Subsequently, the high frequency component generation circuit 222 calculates the high frequency component image  $fhl(x,y)$  by the equation (32) from the original image  $f1(x,y)$  transferred by the CPU 108 and the image  $fus1(x,y)$  after the smoothing processing in the smoothing circuit 221.

$$fh1(x,y) = f1(x,y) - fus1(x,y) \quad (32)$$

Step S323:

Subsequently, the conversion circuit 223 converts the high frequency component image  $fh1(x,y)$  obtained by the high frequency component generation circuit 222, and calculates the converted image  $fchl(x,y)$  by equation (33') based on the high frequency component conversion function  $Ch(x)$  of Fig. 13.

$$fchl(x,y) = Ch(f1(x,y)) \times fh1(x,y) \quad (33')$$

Step S324:

Subsequently, the gradation conversion circuit 224 performs the gradation conversion processing shown by the equation (34) to the image  $fus1(x,y)$  after the smoothing processing in the smoothing circuit 221, using the gradation conversion curve  $F1()$  shown in Fig. 4.

$$fus2(x,y) = F1(fus1(x,y)) \quad (34)$$

In the equation (34), " $fus2(x,y)$ " indicates the pixel value of the smoothed image (output image) after the gradation conversion processing.

Step S325:

Subsequently, the high frequency component addition circuit 225 adds the converted image  $fchl(x,y)$  in the conversion circuit 223 to the image  $fus2(x,y)$  (image after the smoothing processing and gradation conversion processing) after the gradation conversion processing in the gradation conversion circuit 224.



Specifically, then image  $fdr2(x,y)$  after the final DRC processing is calculated by the equation (35).

$$fdr2(x,y) = fus2(x,y) + fchl(x,y) \quad (35)$$

Step S307:

5           Thereafter, as described above, the image  $fdr2(x,y)$  after the DRC processing obtained by the DRC processing circuit 112a is supplied to the gradation conversion circuit 112c, subjected to the gradation conversion processing, and subsequently displayed on  
10 the screen of the image display 111 or outputted onto the film.

As described above, in the present embodiment, since the high frequency component of the original image before the gradation conversion processing is  
15 used, and the converted component is added to the image after the smoothing processing and gradation conversion processing, as compared with the DRC processing which uses the high frequency component of the original image after the gradation conversion, the DRC processing can  
20 be performed using a more precise (less digit drop) high frequency component. In addition to the effect of the first' embodiment, this can provide an effect that a higher frequent component image with a satisfactory restorability can be obtained after the DRC processing.  
25 Furthermore, since the gradation conversion is performed after obtaining and converting the high frequency component, in the above-described first' (or

second' ) embodiment, the processing of calculating and storing the coefficient  $c(x)$  of the gradation conversion curve  $F()$  is unnecessary, and the processing time can be shortened.

5 (4) Fourth' Embodiment: see Figs. 11 and 12

Step S300:

First, as described above, when the X-ray photographing operation starts, the X-ray image obtained by the photographing is transferred to the image processing circuit 112 via the data collection circuit 105 and preprocessing circuit 106 by the control of the CPU 108.

Subsequently, the DRC processing circuit 112a of the image processing circuit 112 executes the processing of the following steps S331 to S335.

15 Step S331:

First, the smoothing circuit 231 performs the smoothing processing shown by the equation (36) to the X-ray image (original image)  $f1(x,y)$  transferred by the CPU 108 to form the smoothed image  $fus1(x,y)$  of the original image  $f1(x,y)$ .

$$fus1(x,y) = \frac{\int_{-d}^d \int_{-d}^d f1(x+x1, y+y1) dx1 dy1}{\int_{-d}^d \int_{-d}^d dx1 dy1} \quad (36)$$

In the equation (36), "d" indicates the constant for determining the mask size  $M \times M$  in the smoothing

processing.

Step S332:

Subsequently, the high frequency component generation circuit 232 calculates the high frequency component image  $fh1(x,y)$  by the equation (37) from the original image  $f1(x,y)$  transferred by the CPU 108 and the image  $fus1(x,y)$  after the smoothing processing in the smoothing circuit 231.

$$fh1(x,y) = f1(x,y) - fus1(x,y) \quad (37)$$

10 Step S333:

Subsequently, the conversion circuit 233 converts the high frequency component image  $fh1(x,y)$  obtained by the high frequency component generation circuit 232, and calculates the converted image  $fchl(x,y)$  by equation (38' ) based on the high frequency component conversion function  $Ch(x)$  of Fig. 13.

$$fchl(x,y) = Ch(f1(x,y)) \times fh1(x,y) \quad (38' )$$

Step S334:

Subsequently, the main memory 109 as the micro coefficient memory means uses the equation (39) to calculate the micro coefficient  $c1(x)$  of the gradation conversion curve  $F1()$ , and stores the coefficient as the table  $c2(x)$ .

$$c2(x) = 1 / \frac{\partial F1(x)}{\partial x} - 1 \quad (39)$$

25 Step S335:

The high frequency component addition circuit 234

adds the converted image  $fclh(x,y)$  in the conversion circuit 233 to the original image  $f1(x,y)$ . Specifically, the image  $fad(x,y)$  after the addition of the high frequency component is calculated by the equation (40).

$$fad(x,y) = f1(x,y) + c2(f1(x,y)) \times fch1(x,y) \quad (40)$$

Step S336:

Subsequently, the gradation conversion circuit 235 performs the gradation conversion processing shown by the equation (41) to the image  $fad(x,y)$  obtained by the high frequency component addition circuit 234 to calculate the image  $fdr2(x,y)$  after the final DRC processing, using the gradation conversion curve  $F1()$  shown in Fig. 4.

$$fdr2(x,y) = F1(fad(x,y)) \quad (41)$$

Step S307:

Thereafter, as described above, the image  $fdr2(x,y)$  after the DRC processing obtained by the DRC processing circuit 112a is supplied to the gradation conversion circuit 112c, subjected to the gradation conversion processing, and subsequently displayed on the screen of the image display 111 or outputted onto the film.

As described above, in the present embodiment, since the high frequency component of the original image before the gradation conversion processing is

used to perform the DRC processing, as compared with the DRC processing which uses the high frequency component of the original image after the gradation conversion processing, the DRC processing can be performed using a more precise (less digit drop) high frequency component. In addition to the effect of the first' embodiment, this can provide an effect that a higher frequent component image with a satisfactory restorability can be obtained after the DRC processing.

10           Additionally, it is needless to say that the object of the present invention is also achieved by providing the system or the apparatus with the memory medium in which the program code of software to realize the functions of the host computer and terminals of the above-described embodiments is stored, and reading and  
15           executing the program code stored in the memory medium by the computer (or CPU or MPU) of the system or the apparatus. In this case, the program code itself read from the memory medium realizes the functions of the  
20           respective embodiments, and the memory medium in which the program code is stored constitutes the present invention.

          Examples of the memory medium for supplying the program code include ROM, floppy disk, hard disk,  
25           optical disk, magnetic optical disk, CD-ROM, CD-R, magnetic tape, nonvolatile memory card, and the like.

          Moreover, the functions of the respective

embodiments are realized by executing the program code read by the computer, but additionally, when the OS or the like operating on the computer performs a part or the whole of the actual processing based on the instruction of the program code, the functions of the above-described embodiments can be realized by the processing. Needless to say, this case is also included in the present invention.

Furthermore, after the program code read from the memory medium is written to the function expansion board inserted to the computer or the memory disposed in the function expansion unit connected to the computer, the CPU or the like disposed in the function expansion board or the function expansion unit performs a part or the whole of the actual processing based on the instruction of the program code, and the functions of the above-described embodiments can also be realized by the processing. Needless to say, this case can also be included.

Although the present invention has been described by some preferable embodiments, it will be understood that the scope of right included in the invention is not limited by the embodiments. On the contrary, the scope of right of the present invention includes all of improvements, modifications, and equivalents included in the scope of the appended claims.